Natural Resources for Human Health
eISSN: 2583-1194

Original Research

Received 30 June 2026
Revised 05 Aug 2026
Accepted 18 Aug 2026

Natural Resources for Human Health 2026, Vol. 6 (18s): 631–647

KEYWORDS:
Krishna Tulsi, Rama Tulsi, drying techniques, phytochemicals, nutritional composition.

Comparative Evaluation of Drying Techniques for Maximizing Nutrient Retention and Phytochemical Profiles in Two Medicinal Tulsi Varieties: An Approach to Reduce Post-Harvest Loss

Raksha Banka[1], Saheli Ghosal[1], Manisha Maity[1*], Joyeta Ghosh[2], Soumi Chakraborty[3]

[1]Research Scholar, Department of Food & Nutrition, Swami Vivekananda University, Telinipara, Barasat - Barrackpore Road, Bara Kanthalia, West Bengal, India, E-mail Id: rakshabanka58@gmail.com
[1]Former Assistant Professor, Department of Food & Nutrition, Swami Vivekananda University, Telinipara, Barasat - Barrackpore Road, Bara Kanthalia, West Bengal, India, E-mail Id: ghosalsaheli1991@gmail.com
[1]Associate Professor and Head, Department of Food & Nutrition, Swami Vivekananda University, Telinipara, Barasat - Barrackpore Road, Bara Kanthalia, West Bengal, India, E-mail Id: manisha.maity04@gmail.com
[2]Assistant Professor, Department of Dietetics & Nutrition, Amity University, Newtown, West Bengal, India, E-mail Id: joyetaghosh01@gmail.com
[3]Assistant Professor, Amity Institute of Food Technology, Amity University, Noida, Uttar Pradesh, India, E-mail Id: soumi.chkrbrt@gmail.com
*Corresponding author email: manisha.maity04@gmail.com

ABSTRACT: Objective:

Tulsi (Ocimum sanctum and Ocimum tenuiflorum) is a pharmacologically important adaptogenic herb with a diverse phytochemical profile and several potential therapeutic applications. However, inappropriate drying practices may adversely affect its nutritional quality, antioxidant potential, and bioactive compounds. This study aimed to compare different drying techniques and identify the most effective method for preserving the nutritional and phytochemical properties of Rama and Krishna Tulsi leaves.

Methods:

Fresh leaves of Rama and Krishna Tulsi were subjected to five drying methods: sun drying, pan drying, hot air oven drying, oven drying at 100°C, and oven drying at 120°C, with fresh leaves serving as controls. The resulting powders were evaluated for proximate composition, functional properties, mineral content, qualitative and quantitative phytochemical constituents, and volatile bioactive compounds using Gas Chromatography-Mass Spectrometry (GC-MS).

Results:

Drying technique influenced the nutritional and phytochemical composition of both Tulsi varieties. Krishna Tulsi dried at 100°C demonstrated superior retention of protein, while Rama Tulsi showed greater retention of carbohydrates under the evaluated drying conditions. GC-MS analysis revealed variations in the volatile bioactive compound

Natural Resources for Human Health
eISSN: 2583-1194

profiles across the different drying treatments, with moderate thermal processing showing comparatively better preservation of bioactive constituents.

Discussion:

The findings indicate that drying temperature and processing conditions play an important role in determining the nutritional and phytochemical quality of Tulsi powders. Oven drying at 100°C provided a favorable balance between moisture removal and retention of key nutritional and bioactive constituents, particularly in Krishna Tulsi. These findings highlight the importance of selecting an appropriate post-harvest drying method to minimize quality deterioration and enhance the functional value of Tulsi for food and nutraceutical applications.

Conclusion:

Oven drying at 100°C was identified as the most effective drying technique for preserving the nutritional quality and phytochemical composition of Krishna Tulsi under the conditions evaluated. The findings support the use of controlled thermal drying as a standardized post-harvest processing approach for developing value-added functional foods and nutraceutical products from Tulsi leaves.

INTRODUCTION

Tulsi is known as a traditional herb and most widely used in ayurvedic medicines [1]. Its powder form is available in the market, though people prefer home-based methods for preparation and preserving it [2]. Medicinal and aromatic plants are highly susceptible to post-harvest deterioration because of their high moisture content and improper harvesting, handling, storage and processing practices. It has been estimated that post-harvest losses of medicinal plants range from approximately 10–40% in Asian countries, including India, resulting in substantial losses of bioactive compounds and reduced medicinal quality. Therefore, appropriate post-harvest processing, particularly drying, is essential to preserve their phytochemical composition and therapeutic efficacy [3].

They use different methods for powder preparation, on the basis of which their quality differs. Thus, a standardized method for drying and processing Tulsi leaves into powder should be established and implemented to get maximum benefits from it. Two different varieties of Tulsi leaves, namely, *Ocimum sanctum* and *Ocimum tenuiflorum* (Rama and Krishna Tulsi, respectively), are known for their nutritional and therapeutic benefits. Drying Tulsi leaves plays a key role in preserving their nutritional and medicinal value, but excessive heat during this process can lead to the loss of important nutrients present in them [4]. Different drying methods have been employed for the preparation of Tulsi powder, including sun drying, pan-drying, hot-air oven drying and microwave drying. These techniques differ considerably in their ability to preserve nutritional and phytochemical constituents. Studies have shown that drying conditions significantly influence the retention of bioactive compounds, antioxidant activity and volatile constituents. For example, in basil leaves, increasing convective drying temperature improved total phenolic content by an average of 16.28%, while increasing microwave power improved phenolic retention by 27.98%. However, higher drying temperatures also reduced anthocyanin content and antioxidant activity, and altered the volatile phytochemical profile, demonstrating that drying conditions play a crucial role in determining the quality of the final dried product [5].

Therefore, it is important to follow proper drying methods that reduce heat exposure and help retain the quality of compounds in Tulsi powder [6]. Tulsi leaves can be used in many forms, but the powdered form is currently the most effective due to its ease of use. It can be included in breakfast drinks or added while cooking, such as by mixing it into dough [7].

Although several studies have investigated drying methods in basil and medicinal herbs, comparative information on different household drying techniques for both Rama and Krishna Tulsi, together with nutritional, mineral and GC-MS phytochemical evaluation, remains limited. This study aims to provide a comparative analysis by preparing home-based Tulsi powders from two varieties using different drying techniques at varied temperatures. The resulting powders were evaluated for their nutritional,

functional and phytochemical properties. By identifying the most effective preparation techniques that preserve their therapeutic properties, this research supports the development of a functional food product that can be easily included in daily diets.

METHODOLOGY

Preparation of Sample

Two varieties of Tulsi leaves, Krishna Tulsi (*Ocimum tenuiflorum*) and Rama Tulsi (*Ocimum sanctum*), were collected from a local market in Kolkata. One independent leaf batch of each Tulsi variety was collected from the local market and divided into six processing groups, comprising one raw sample and five drying treatments. Six samples were prepared for each variety, comprising one raw (undried) sample and five samples subjected to different drying methods, including sun drying, pan drying, hot-air oven drying, and oven drying at 100°C and 120°C, following standard processing methods described in previous studies [8]. The fresh Rama and Krishna Tulsi leaves used as control samples are shown in Figure 1. For the sun-drying treatment, the leaves were dried under direct sunlight, as illustrated in Figure 2, while the pan-drying process is shown in Figure 3. The leaves subjected to oven drying at 100°C and 120°C are shown in Figure 4. The hot-air oven-drying process used for the leaves is presented in Figure 5. Following the drying treatments, the leaves were ground into a fine powder using a mixer grinder. The final powdered samples were ensured to be completely free from moisture, in accordance with the guidelines described in previous studies [9]. The prepared powders were subsequently used for further nutritional, functional, mineral, and phytochemical analyses.

Inclusion Criteria:

a. Two specific varieties of Tulsi leaves, namely Rama Tulsi (*Ocimum sanctum*) and Krishna Tulsi (*Ocimum tenuiflorum*) were selected for the study, both collected from a local market in Kolkata.

b. Only the leaves of the selected two species were used.

c. Fresh, clean and undamaged leaves were included for processing.

Exclusion Criteria:

a. Other varieties of Tulsi such as Vana Tulsi (*Ocimum gratissimum*) and Kapoor Tulsi (*Ocimum kilimandscharicum*), were excluded.

b. Plant parts other than leaves, including stems, flowers and seeds, were not considered.

c. Leaves that were damaged, discolored or otherwise impure were excluded from the study.

Fresh leaves of Rama and Krishna Tulsi were subjected to five different drying treatments, along with fresh leaves serving as controls. The drying treatments applied to both varieties are presented in Table 1.

Table 1. Drying treatments applied to Rama and Krishna Tulsi leaves

Sample Code	Sample Name	Drying Methods
R1	Rama Tulsi Raw Leaves	Fresh (undried control)
R2	Rama Tulsi Pan-Dried Leaves	Dried using pan drying (direct heat on a pan)
R3	Rama Tulsi Hot Air Oven-Dried Leaves	Dried in a hot air oven (controlled temperature)
R4	Rama Tulsi Oven-Dried Leaves	Oven dried at 120°C
R5	Rama Tulsi Oven-Dried Leaves	Oven dried at 100°C

R6	Rama Tulsi Sun-Dried Leaves	Naturally dried under direct sunlight
K1	Krishna Tulsi Raw Leaves	Fresh (undried control)
K2	Krishna Tulsi Pan-Dried Leaves	Dried using pan drying (direct heat on a pan)
K3	Krishna Tulsi Hot Air Oven-Dried Leaves	Dried in a hot air oven (controlled temperature)
K4	Krishna Tulsi Oven-Dried Leaves	Oven dried at 120°C
K5	Krishna Tulsi Oven-Dried Leaves	Oven dried at 100°C
K6	Krishna Tulsi Sun-Dried Leaves	Naturally dried under direct sunlight



Figure 1: Fresh (undried) Rama and Krishna Tulsi leaves



Figure 2: Sun-drying process used for Rama and Krishna Tulsi leaves



Figure 3: Pan-drying process used for for Rama and Krishna Tulsi leaves



Figure 4: Oven-drying process (at 100°C and 120 °C) used for Rama and Krishna Tulsi leaves



Figure 5: Hot air oven-drying process used for Rama and Krishna Tulsi leaves

Proximate composition analysis: The proximate composition of the samples, including moisture and ash content was analyzed using standard biochemical methods as described by AOAC [10] with slight modifications. Moisture was determined

using a hot air oven at 100°C until constant weight. Ash was calculated after incineration in a muffle furnace (Infitek, FNC BX1700 Series). Fat was extracted by the Soxhlet method using hexane following the method of previous studies [11]. Protein content was analyzed using the method as described by Lowry [12]. Carbohydrate was determined using the method as described by Yemm and Willis [13] with slight modifications.

Functional properties:

Sample Preparation For phytochemical analysis, 10 g of dried Tulsi leaf powder of each variety was soaked in 100 mL of 95% ethanol for 24 hours at room temperature. The mixture was filtered using Whatman Grade 1 filter paper to separate the extract [14]. The filtrate was then used for quantitative screening of the phytochemical as per the method described by Anwar et al. [15].

Water absorption capacity, foaming capacity and emulsion capacity were determined using the methods as described previously [16] with slight modifications. Water absorption capacity was analyzed using the Mettler Toledo HG63 Moisture Analyzer. Foaming capacity and emulsion capacity were determined using standard separation techniques as described previously [17] with slight modifications. Oil absorption capacity was assessed based on fat content, which was extracted through the Soxhlet method as described by AOAC [10] with slight modifications.

Mineral content analysis: Calcium, magnesium, iron, and potassium content were estimated using a PerkinElmer Analyst 800 atomic absorption spectrophotometer and Systronics flame photometer (Model 128) by following the method outlined in previous studies [18] with slight modifications. Phosphorus content was determined according to the procedure described in previous studies [19] using standard colorimetric analysis techniques.

Qualitative and quantitative phytochemical analysis: Phytochemical analysis of the extracts was conducted using standard methods [20] with minor changes. For quantitative estimation, a Shimadzu UV-Vis spectrophotometer (Model UV-1800) was used to measure absorbance at 400 nm. For the identification of aromatic and semi-aromatic compounds, Gas Chromatography-Mass Spectrometry (GC-MS) was performed using a Thermo Scientific TRACE 1300 system.

Statistical Analysis: All analytical measurements were performed in triplicate as technical replicates ($n = 3$). These measurements were obtained from the same processed sample and therefore represent technical rather than biological replicates. Results are presented as mean ± standard deviation. The results were analyzed using one-way ANOVA at a significance level of $p \leq 0.05$, followed by Tukey's post hoc test for pairwise comparisons to determine significant differences among the experimental groups [21]. The experimental replication was selected based on the analytical triplicate design and comparable published studies investigating the effects of drying treatments on medicinal and aromatic plant materials [1,5,6,18]. A priori power analysis was not performed.

Ethical statement: This study did not involve human participants or animal experiments. Only plant materials (Tulsi leaves) were used.

RESULTS

Proximate composition analysis: Analysis of proximate composition has been presented in Table 2 which revealed that Rama Tulsi (R4) had the highest carbohydrate content (80.83%), while R1 showed the highest protein content (25%). Among all formulations, R2 recorded the highest fat content (0.5%), whereas R1 had the maximum moisture content (5%) and ash content (4%). In comparison with Krishna Tulsi samples, K5 exhibited the highest protein content (36.18%) and the highest carbohydrate content (52.12%). K2 was found to contain moderate levels of both protein and carbohydrate, along with a balanced composition of other nutrients. Figure 6, 7 8 and 9 shows the results of protein content, moisture content, fat content and ash content of the samples analysed respectively.



Figure 6: Determination of protein content of dried Rama and Krishna Tulsi leaves powder



Figure 7: Determination of moisture content of dried Rama and Krishna Tulsi leaves powder



Figure 8: Determination of fat content of dried Rama and Krishna Tulsi leaves powder

Natural Resources for Human Health
eISSN: 2583-1194



Figure 9: Determination of ash content of dried Rama and Krishna Tulsi leaves powder

Table 2. Proximate composition of Rama and Krishna Tulsi leaf powders

Sample		Proximate Composition				
		Carbohydrate	**Protein**	**Fat**	**Moisture**	**Ash**
Rama Tulsi (*Ocimum sanctum*)	**R1**	65 ±0.05[a]	25 ±0.02 [a]	1 ±0.01[a]	5 ±0.5 [a]	4 ±0.02 [a]
	R2	67.58 ±0.03[bce]	9.92±0.04 [bacdf]	0.5±0.02 [bef]	2±0.4 [bad]	20±0.1 [bacdf]
	R3	69.10±0.04[cabdf]	9.01±0.03 [cde]	0.3±0.02 [cadef]	1±0.3 [cbf]	05±0.01 [cae]
	R4	80.83±0.06 [dace]	8.87±0.02 [dcef]	0.3±0.02 [daf]	0±0.1 [dabf]	10±0.02 [dbce]
	R5	75.76±0.05 [eab]	14.04±0.05 [eabcf]	0.2±0.01 [eacd]	1±0.3 [ebdf]	10±0.02 [eacd]
	R6	75.06±0.05 [fbce]	15.64±0.06 [fae]	0.3±0.02 [face]	3±0.01 [fabc]	05±0.01 [fbe]
Krishna Tulsi (*Ocimum tenuiflorum*)	**K1**	60±0.02 [ga]	28±0.03 [ga]	1.5±0.05 [ga]	6±0.02 [g]	4.5±0.02 [g]
	K2	62.29±0.04 [hijlb]	15.41±0.04 [hgjk]	0.3±0.02 [hgijkl]	2±0.4 [hjb]	20±0.1 [hgikl]
	K3	61.24±0.03 [ighc]	31.20±0.05 [igjkl]	0.3±0.02 [ihjkl]	1±0.3 [igjkc]	10±0.02 [ihjl]
	K4	55.16±0.02 [ijld]	34.64±0.06 [ihikl]	0.2±0.01 [ighk]	0±0.1 [igikld]	10±0.02 [ighi]

	K5	52.12±0.02 kghle	36.18±0.07 khij	0.7±0.07 kgil	1±0.3 kijle	10±0.02 khjle
	K6	58.73±0.03 lijklf	30.77±0.04 lghiklf	0.5±0.05 lgijl	0±0.1 lghkl	10±0.02 lhjkf

Samples were analysed in triplicate. Mean and ±SD were calculated. Significant differences were denoted in the same column by different letters (P≤ 0.05) from each other.

[R1: Rama tulsi raw leaves; R2: Rama tulsi pan-dried; R3: Rama tulsi hot air oven dried; R4: Rama tulsi oven dried at 120°C; R5: Rama tulsi oven dried at 100°C; R6: Rama tulsi sun dried, K1: Krishna tulsi raw leaves; K2: Krishna tulsi pan dried; K3: Krishna tulsi hot air oven dried; K4: Krishna tulsi oven dried at 120°C; K5: Krishna tulsi oven dried at 100°C; K6: Krishna tulsi dried under sun].

Functional properties analysis: In the Rama Tulsi group, R4 showed the highest water absorption (2 ml/g) and oil absorption (0.8 ml/g). In the Krishna Tulsi group, K4 had the maximum water solubility (1.9 ml/g), whereas K5 showed the highest oil capacity (1.1 ml/g). Foaming capacity was minimal across all samples, with little variation. No emulsion capacity was observed in either group. The detailed results of functional properties are presented in Table 3. Figure 10 and 11 shows the results of WAC, OAC and FC of the tests respectively.



Figure 10: Water absorption capacity (WAC) and Oil Absorption Capacity (OAC) analysis of dried Rama and Krishna Tulsi leaves powder



Figure 11: Foaming capacity analysis of dried Rama and Krishn Tulsi leaves powder

Natural Resources for Human Health
eISSN: 2583-1194

Table 3. Functional properties of Rama and Krishna Tulsi leaf powders

Sample		Functional Properties			
		Water absorption capacity (ml/g)	Oil absorption capacity (ml/g)	Foaming Capacity (ml/g)	Emulsion Capacity (%)
Rama Tulsi (*Ocimum Sanctum*)	R1	1.6± 0.2^{a}	0.7± 0.2^{a}	0± 0.0^{a}	Not detected
	R2	1.8± 0.2^{bacde}	0.4± 0.0^{badef}	0.2± 0.1^{bcf}	Not detected
	R3	1.7± 0.2^{cbf}	0.5± 0.2^{cabde}	0.1± 0.05^{caef}	Not detected
	R4	2± 0.15^{dabcf}	0.8± 0.1^{dbef}	0.1± 0.05^{dace}	Not detected
	R5	2± 0.15^{edf}	1± 0.0^{eac}	0.1± 0.05^{ebcf}	Not detected
	R6	1.6± 0.2^{fad}	0.8± 0.1^{facde}	0± 0.0^{fbe}	Not detected
Krishna Tulsi (*Ocimum tenuiflorum*)	K1	1.5± 0.2^{ga}	1.1± 0.15^{ga}	0± 0.0^{g}	Not detected
	K2	1.5± 0.2^{hjkb}	0.6± 0.08^{hgik}	0± 0.0^{hgijlb}	Not detected
	K3	1.6± 0.2^{igjk}	0.7± 0.2^{ighjlc}	0± 0.0^{ihc}	Not detected
	K4	1.9± 0.1^{ighid}	0.4± 0.05^{igl}	0.2± 0.1^{jhk}	Not detected
	K5	1.9± 0.1^{kgj}	1.1± 0.15^{khjle}	0.1± 0.05^{kgile}	Not detected
	K6	1.5± 0.2^{ljk}	1± 0.0^{lhif}	0± 0.0^{lghkf}	Not detected

Samples were analysed in triplicate. Mean and ±SD were calculated. Significant differences were denoted in the same column by different letters (P≤ 0.05) from each other.

[R1: Rama tulsi raw leaves; R2: Rama tulsi pan-dried; R3: Rama tulsi hot air oven dried; R4: Rama tulsi oven dried at 120°C; R5: Rama tulsi oven dried at 100°C; R6: Rama tulsi sun dried, K1: Krishna tulsi raw leaves; K2: Krishna tulsi pan dried; K3: Krishna tulsi hot air oven dried; K4: Krishna tulsi oven dried at 120°C; K5: Krishna tulsi oven dried at 100°C; K6: Krishna tulsi dried under sun].

Mineral content analysis: In the Rama Tulsi group, R2 exhibited the highest levels of calcium (1.5%) and iron (1.0 mg/100g), while R4 showed the maximum levels of phosphorus (0.5%). Among the Krishna Tulsi samples, K2 had the highest calcium (1.8%) and potassium (2.3%) levels, K5 recorded the highest magnesium content (1.0%), and K4 showed the highest

phosphorus concentration (0.7%). Overall, potassium content remained relatively consistent across both groups. Table 4 shows the mineral content analysis of the formulated products.

Table 4. Mineral composition of Rama and Krishna Tulsi leaf powders

Sample		Mineral Content				
		Calcium (%)	Magnesium (%)	Phosphorus (%)	Iron (mg/100gm)	Potassium (%)
Rama Tulsi (*Ocimum Sanctum*)	R1	1.2 ± 0.05^{a}	0.6 ± 0.02^{a}	0.4±0.02^{a}	1±0.05^{a}	1.6±0.05 a
	R2	1.5 ± 0.3^{bdf}	0.8 ± 0.15^{bacef}	0.4 ± 0.1^{bcde}	1.0 ± 0.15^{badef}	2.0 ± 0.3^{bac}
	R3	1.3 ± 0.3^{cb}	0.8 ± 0.2^{cbef}	0.4 ± 0.2^{cabde}	0.8 ± 0.2^{cdef}	1.8 ± 0.3^{caf}
	R4	1.3 ± 0.2^{dac}	0.7 ± 0.15^{daef}	0.5 ± 0.1^{dabcf}	0.9 ± 0.15^{dbef}	1.8 ± 0.25^{dbc}
	R5	1.4 ±0.25^{ebf}	0.6 ±0.1^{ebcd}	0.4 ±0.08^{ebd}	0.8±0.12^{eabcdf}	1.7 ±0.2^{eaf}
	R6	1.3±0.15^{fcde}	0.6 ±0.1^{fabd}	0.5 ±0.1^{fabe}	1.0±0.12^{facde}	1.7±0.18^{fabcd}
Krishna Tulsi (*Ocimum tenuiflorum*)	K1	1.6 ±0.2^{ga}	0.7 ±0.1^{ga}	0.7±0.1^{g}	1.1±0.15^{ga}	2.0±0.25^{g}
	K2	1.8 ±0.2^{hgjlb}	0.6 ±0.15^{hgl}	0.8 ±0.12^{hijkb}	1.2 ±0.15^{hgikb}	2.3 ±0.3^{hik}
	K3	1.6 ±0.2^{ihkc}	0.8 ±0.15^{ihk}	0.8 ±0.15^{igjl}	1.0 ±0.15^{ighjkc}	2.0 ±0.25^{iglc}
	K4	1.6 ±0.2^{igi}	0.9 ±0.15^{jhikd}	0.7 ±0.1^{ighikl}	1.1 ±0.15^{jhld}	2.1 ±0.25^{igld}
	K5	1.7 ±0.2^{khjle}	1.0 ±0.1^{kghijle}	0.5 ±0.1^{kgil}	1.0 ±0.15^{kgijl}	2.0 ±0.25^{khe}
	K6	1.6 ±0.2^{lghf}	0.8 ±0.15^{lhij}	0.7 ±0.1^{lijkf}	1.2 ±0.15^{lghij}	2.0 ±0.25^{likf}

Samples were analysed in triplicate. Mean and ±SD were calculated. Significant differences were denoted in the same column by different letters (P≤ 0.05) from each other.

[R1: Rama tulsi raw leaves; R2: Rama tulsi pan-dried; R3: Rama tulsi hot air oven dried; R4: Rama tulsi oven dried at 120°C; R5: Rama tulsi oven dried at 100°C; R6: Rama tulsi sun dried, K1: Krishna tulsi raw leaves; K2: Krishna tulsi pan dried; K3:

Krishna tulsi hot air oven dried; K4: Krishna tulsi oven dried at 120°C; K5: Krishna tulsi oven dried at 100°C; K6: Krishna tulsi dried under sun].

Qualitative phytochemical analysis: The qualitative phytochemical profiles of Rama and Krishna Tulsi leaf powders are presented in Table 5. Alkaloids, glycosides, tannins, flavonoids, and oxalates were detected in all samples of both Tulsi varieties, whereas saponins were not detected in any of the samples.

Table 5. Qualitative phytochemical profile of Rama and Krishna Tulsi leaf powders

Sample		Qualitative phytochemical tests					
		Alkaloid	Glycoside	Tannin	Flavonoid	Oxalate	Saponins
Rama Tulsi (*Ocimum Sanctum*)	R1	+	+	+	+	+	-
	R2	+	+	+	+	+	-
	R3	+	+	+	+	+	-
	R4	+	+	+	+	+	-
	R5	+	+	+	+	+	-
	R6	+	+	+	+	+	-
Krishna Tulsi (*Ocimum tenuiflorum*)	K1	+	+	+	+	+	-
	K2	+	+	+	+	+	-
	K3	+	+	+	+	+	-
	K4	+	+	+	+	+	-
	K5	+	+	+	+	+	-
	K6	+	+	+	+	+	-

[R1: Rama tulsi raw leaves; R2: Rama tulsi pan-dried; R3: Rama tulsi hot air oven dried; R4: Rama tulsi oven dried at 120°C; R5: Rama tulsi oven dried at 100°C; R6: Rama tulsi sun dried, K1: Krishna tulsi raw leaves; K2: Krishna tulsi pan dried; K3: Krishna tulsi hot air oven dried; K4: Krishna tulsi oven dried at 120°C; K5: Krishna tulsi oven dried at 100°C; K6: Krishna tulsi dried under sun].

Quantitative phytochemical analysis: The quantitative phytochemical composition of Rama and Krishna Tulsi leaf powders is presented in Table 6. In Rama Tulsi, R2 showed the highest alkaloid (1.0%), glycoside (0.6%), and flavonoid (1.2%) contents, whereas R1 showed the highest tannin (0.5%) and oxalate (0.6%) contents. Among the Krishna Tulsi samples, K2 exhibited the highest alkaloid (1.2%), glycoside (0.8%), and flavonoid (1.4%) contents, while K1 showed the highest tannin (0.6%) and oxalate (0.9%) contents. Overall, Krishna Tulsi exhibited comparatively higher concentrations of several quantified phytochemicals than Rama Tulsi.

Table 6: Quantitative phytochemical profile of Rama and Krishna Tulsi leaf powders

Sample		Quantitative phytochemical tests				
		Alkaloid (%)	Glycoside (%)	Tannin (%)	Flavonoid (%)	Oxalate (%)
Rama Tulsi (*Ocimum Sanctum*)	R1	0.9 ±0.2 [a]	0.6 ±0.15 [a]	0.5 ±0.1 [a]	1.0 ±0.15 [a]	0.6 ±0.15 [a]

	R2	1.0 ±0.15 bad	0.6 ±0.15 bdef	0.5 ±0.1 bacef	1.2 ±0.2 bacdf	0.6 ±0.15 bcef
	R3	0.8 ±0.15 cde	0.5 ±0.1 cabdef	0.4 ±0.1 cab	0.6 ±0.15 cbdf	0.5 ±0.1 caef
	R4	0.8 ±0.15 dbe	0.5 ±0.1 dabcf	0.4 ±0.1 dac	1.0 ±0.15 adbef	0.5 ±0.1 dae
	R5	0.7 ±0.15 eac	0.4 ±0.1 ead	0.3 ±0.08 ead	0.9 ±0.15 eabcf	0.4 ±0.1 ebcf
	R6	0.6 ±0.15 fabcd	0.4 ±0.1 fabe	0.3 ±0.08 fabc	1.0 ±0.15 facde	0.5 ±0.1 fcd
Krishna Tulsi (*Ocimum tenuiflorum*)	**K1**	1.0 ±0.15 ga	0.8 ±0.12 ga	0.6 ±0.1 g	1.4 ±0.2 ga	0.9 ±0.12 g
	K2	1.2 ±0.18 hgijk	0.8 ±0.12 hijklb	0.7 ±0.1 hgij	1.4 ±0.2 hglb	0.8 ±0.12 hk
	K3	0.9 ±0.12 ihl	0.6 ±0.1 igkc	0.5±0.08 ighjk	0.7 ±0.1 ijklc	0.6 ±0.1 igjlc
	K4	1.0 ±0.15 jghl	0.7 ±0.1 jghikd	0.6 ±0.1 jghi	1.2 ±0.18 jikld	0.7 ±0.1 jikd
	K5	0.9 ±0.12 khle	0.6 ±0.1 khie	0.5 ±0.08 kgijl	1.1 ±0.16 kijle	0.6 ±0.1 kgh
	K6	0.8 ±0.12 lhk	0.7 ±0.1 lghif	0.5 ±0.08 lgif	1.2 ±0.18 lhijkf	0.8 ±0.12 lghj

Samples were analysed in triplicate. Mean and ±SD were calculated. Significant differences were denoted in the same column by different letters (P≤ 0.05) from each other.

[R1: Rama tulsi raw leaves; R2: Rama tulsi pan-dried; R3: Rama tulsi hot air oven dried; R4: Rama tulsi oven dried at 120°C; R5: Rama tulsi oven dried at 100°C; R6: Rama tulsi sun dried, K1: Krishna tulsi raw leaves; K2: Krishna tulsi pan dried; K3: Krishna tulsi hot air oven dried; K4: Krishna tulsi oven dried at 120°C; K5: Krishna tulsi oven dried at 100°C; K6: Krishna tulsi dried under sun].

DISCUSSION

Both Rama Tulsi and Krishna Tulsi have shown significant levels of proximate compounds such as carbohydrates, proteins, fats and others, which align with findings reported in previous studies [22, 23], which emphasized the nutritional potential of Tulsi leaves. However, Krishna Tulsi, which was subjected to oven-drying, exhibited comparatively higher nutrition retention, particularly in terms of protein and mineral content. This observation is consistent with earlier research indicating that drying methods significantly influence the preservation and bioavailability of nutrients in Rama Tulsi [24, 25]. Their study suggested

that oven-drying at controlled temperatures (50°C-60°C) helps retain active constituents more effectively than traditional sun-drying or air-drying techniques [24].

The observed differences in moisture and oil absorption between the two Tulsi varieties suggest underlying variations in cellular structure retention following the drying process [26, 27]. Krishna Tulsi likely retained a more porous microstructure conducive to enhanced oil absorption, an important characteristic for applications in functional foods and nutraceutical formulations, owing to its processing through oven-drying. These results align well with previous studies that have demonstrated the influence of drying methods on the surface morphology and porosity of herbal leaves, which directly impact their absorption capacities [26, 27].

The mineral content analysis indicated a significant presence of essential minerals, such as magnesium, calcium, potassium, phosphorus and iron, especially in the oven-dried Tulsi leaves. This higher mineral concentration may be due to better nutrient absorption and translocation in plants grown in specific regions, particularly those located at higher altitudes. These findings are in line with previous studies that suggest mineral content in Tulsi is influenced not only by the plant variety but also by environmental conditions and processing methods [28, 29]. Among these, oven drying appears to be the most effective in preserving nutrient levels.

Furthermore, both qualitative and quantitative phytochemical analyses revealed notable differences between the two Tulsi types. GC-MS analysis confirmed the presence of several bioactive constituents in Tulsi. Variations in chromatographic peak profiles among different drying methods suggested that thermal processing influences the retention and degradation of volatile phytochemicals. Moderate drying conditions preserved a greater diversity of compounds, whereas higher drying temperatures resulted in a reduction of certain thermolabile constituents. These findings support the quantitative phytochemical results obtained in the present study, according to which, Krishna Tulsi exhibited higher levels of flavonoids and glycosides, suggesting a richer content of polyphenolic compounds. This implies a stronger antioxidant potential and greater therapeutic value. These results are consistent with studies which highlight that phytochemical composition can vary depending on the altitude, climate and timing of harvest [30, 31].

Statistical evaluation of both Krishna Tulsi and Rama Tulsi revealed significant differences in their biochemical profiles, particularly in carbohydrate and protein content. Krishna Tulsi exhibited a higher protein concentration, whereas Rama Tulsi had a greater carbohydrate content as per the findings of previous research. Mineral content, including potassium, phosphorus, calcium and iron, was notably higher in Krishna Tulsi, while Rama Tulsi showed comparatively lower values. In terms of tannins, glycosides and oxalate, both varieties of Tulsi leaves have shown remarkable differences. These phytochemicals were found in appreciable amounts, aligning with established studies that support their functional and therapeutic relevance [32].

CONCLUSION

The medicinal properties of both Rama Tulsi (*Ocimum sanctum*) and Krishna Tulsi (*Ocimum tenuiflorum*) leaf powders have been highlighted in this study. The phytochemical analysis revealed significant levels of bioactive compounds in both varieties, particularly alkaloids, flavonoids, glycosides and tannins. However, Krishna Tulsi (*Ocimum tenuiflorum*) exhibited slightly higher concentrations of phytochemicals than Rama Tulsi (*Ocimum sanctum*). GC-MS analysis further confirmed the presence of several medicinally important phytochemicals in both Tulsi varieties and demonstrated that drying methods significantly influenced the volatile phytochemical profile. Among the different drying techniques evaluated, oven drying at 100°C proved to be the most effective method for preserving these bioactive constituents. The findings indicate that the selection of an appropriate drying method is essential for maintaining the phytochemical composition and therapeutic potential of Tulsi leaves. Therefore, Tulsi leaf powder can be considered a valuable medicinal herb with promising applications in the pharmaceutical, nutraceutical, food and healthcare industries. Further research is recommended to identify and quantify additional bioactive compounds and to better understand their therapeutic roles, thereby supporting the development of functional products and promoting human health.

LIMITATIONS OF THE STUDY

The study evaluated two Tulsi varieties obtained from a single geographical source, which may limit the generalizability of the findings to different cultivars, environmental conditions, and geographical regions. The study also assessed a limited range of drying methods and temperature conditions; factors such as drying duration, humidity, and airflow were not comprehensively evaluated.

Furthermore, GC-MS analysis does not provide a complete profile of all phytochemicals present in Tulsi. Future studies should incorporate complementary analytical techniques such as HPLC or LC-MS for comprehensive characterization. The stability of nutritional and phytochemical constituents during prolonged storage was also not assessed. Further research involving multiple independent batches, different geographical sources, optimized drying conditions, and storage studies is therefore recommended to establish standardized drying protocols.

ACKNOWLEDGEMENT

The author would like to express sincere gratitude to Swami Vivekananda University, Barrackpore, West Bengal, India, for offering the opportunity to carry out research work.

FUNDING

The authors received no financial support for the research, authorship, or publication of this article.

DISCLOSURE OF INTEREST

The authors report there are no competing interests to declare.

AUTHOR CONTRIBUTIONS

Raksha Banka conceptualized and designed the study, performed the experiments, collected and analyzed the data, and prepared the original manuscript. Saheli Ghosal contributed to the study methodology, data analysis, and critical revision of the manuscript. Manisha Maity supervised the research, contributed to the study design, reviewed and edited the manuscript, and approved the final version for publication. Joyeta Ghosh and Soumi Chakraborty critically reviewed the manuscript, provided scientific inputs, and contributed to the interpretation of the results. All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

DECLARATION OF GENERATIVE AI USE

The authors report that generative artificial intelligence (AI) was not used in the research, data analysis, or preparation of this manuscript.

DATA AVAILABILITY STATEMENT

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

REFERENCES

[1] Siddiqui, T., Mallick, M. N., & Sharma, V. (2026). Exploring the Therapeutic Potential of Ocimum sanctum and Phanera variegata in Breast Cancer Treatment: A Promising Natural Approach. *Anti-cancer agents in medicinal chemistry*, *26*(3), 239-253.

[2] Sahu O. A comprehensive review on Ocimum tenuiflorum. J Ayurveda Integr Med Sci. 2025;10(7):193-200. doi:10.21760/jaims.10.7.29.

[3] Eapen AS, Bhosale YK, Roy S. A review on novel techniques used for drying medicinal plants and its applications. Int J Biomater. 2025;2025:4533070. doi:10.1155/ijbm/4533070

[4] Kaur, P., Sharma, I., Kumar, R., Sharma, S., Shiwani, K., Sharma, A., & Sharma, A. (2026). In Vitro Efficacy of Tulsi (Ocimum sanctum) based Extract against Soil Borne Fungi. *International Journal of Economic Plants*, *11*(4), 435-440.

[5] Kaushik P, Gahalayan A, Parasar S, Rani M, Khurana N, Dogra S, Pandey P. Exploring the multifaceted health benefits of natural dietary sources: Antimicrobial, antioxidant, anticancer, and antidiabetic properties. Recent Pat Biotechnol. 2026;20(4):403-421. doi:10.2174/0118722083375459250801073140.

[6] Panigrahi, S., Acharya, P., & Priyadarshni, K. (2026). Comparative Antibacterial activity of Azadirachta indica and Ocimum sanctum against Escherichia coli and Staphylococcus aureus.

[7] Saini, G., Singh, B., Durgapal, S., Anand, A., Chandel, K., & Raza, A. (2026). Harnessing Nature: An Explicative Review on Nano Formulations of Indian Medicinal Plants for Antifungal Applications. *Current Bioactive Compounds*, *22*(8), E15734072365253.

[8] Akbar FN, Mahmood S, Mueen-ud-din G, Yamin M, Murtaza MA. Exploring the effects of drying method and temperature on the quality of dried basil (*Ocimum basilicum* L.) leaves: A sustainable and eco-friendly drying solution. Resources. 2024;13(9):121. doi:10.3390/resources13090121

[9] Adeniran AA, Abuh SA, Adeboye OL, et al. Comparative micromorphological study and phytochemical constituents of *Stachytarpheta cayennensis* (Rich.) Vahl and *Stachytarpheta angustifolia* (Mill.) Vahl. Discover Plants. 2025;2:28. doi:10.1007/s44372-025-00098-3

[10] AOAC International. Official methods of analysis of AOAC International. 18th ed. Gaithersburg (MD): AOAC International; 2011.

[11] Boufetacha M, Gharibi E, Benali M. Optimising supercritical carbon dioxide extraction of rosmarinic acid from *Rosmarinus officinalis* L. and enhancing yield through Soxhlet coupling. Processes. 2025;13(3):655. doi:10.3390/pr13030655

[12] Lowry OH, Rosebrough NJ, Farr AL, Randall RJ. Protein measurement with the Folin phenol reagent. J Biol Chem. 1951;193(1):265-275. doi:10.1016/S0021-9258(19)52451-6.

[13] Yemm EW, Willis AJ. The estimation of carbohydrates in plant extracts by anthrone. Biochem J. 1954;57(3):508-514. doi:10.1042/bj0570508.

[14] Ballester ELC, Costa WGS, do Nascimento Ferreira CH, Retcheski MC, Cazarolli LH, Schwengber GH, et al. Dietary *Ocimum gratissimum* essential oil improves the antioxidant status and maintains the performance of *Macrobrachium rosenbergii* juveniles. Appl Sci. 2025;15(5):2745. doi:10.3390/app15052745

[15] Anwar S, Raut R, Alhumaydhi FA. A comprehensive investigation on alleviating oxidative stress and inflammation in hyperglycaemic conditions through in vitro experiments and computational analysis. Saudi J Biol Sci. 2024;31(7):104003. doi:10.1016/j.sjbs.2024.104003

[16] Baliga MS, Jimmy R, Thilakchand KR, Sunitha V, Bhat NR, Saldanha E, et al. *Ocimum sanctum* L. (Holy Basil or Tulsi) and its phytochemicals in the prevention and treatment of cancer. Nutr Cancer. 2013;65(Suppl 1):26-35. doi:10.1080/01635581.2013.785010

[17] Mallikarjun S, Rao A, Rajesh G, Shenoy R, Pai M. Antimicrobial efficacy of Tulsi leaf (*Ocimum sanctum*) extract on periodontal pathogens: An in vitro study. J Indian Soc Periodontol. 2016;20(2):145-150. doi:10.4103/0972-124X.175177

[18] Nguyen VT, Vuong QV, Bowyer MC, Altena I, Scarlett CJ. Effects of different drying methods on bioactive compound yield and antioxidant capacity of Phyllanthus amarus. Dry Technol. 2015;33(8):1006-1017. doi:10.1080/07373937.2015.1013197.

[19] Dhiman S, Tyagi A, Sarma K, Sharma H, Sharma M. Tulsi (Ocimum tenuiflorum L.): A comprehensive review on medicinal potential, cultural importance, essential oil chemo-diversity and genetic basis of purple coloration. Int J Pharm Sci. 2026;4(8):368-387. doi:10.5281/zenodo.21779735.

[20] Soni P. Phytochemical analysis of Ocimum tenuiflorum (Tulsi): A review. Int J Sci Res. 2025;14(6):1363-1364. doi:10.21275/MR25619135131.

[21] Suresh K, Kumaraswamy M, Sundaravadanam H, Kadirvel V, Thirumavalavan V, Ganesan ND. Engineering perspectives on drying technologies of medicinal plants: A review on kinetic modelling and bioactive compounds retention. Appl Sci Eng Prog. 2026;19(1):7900. doi:10.14416/j.asep.2025.10.003

[22] Kamal MM, Haque S, Suvo TK, Akter P, Mia MS, Shah MSMS, et al. Nutritional composition, mineral profile, bioactive phytochemicals, and antioxidant activities of selected edible weeds: A comprehensive analysis. Food Sci Nutr. 2025;13(7):e70635. doi:10.1002/fsn3.70635

[23] Ajmal M, Nijabat A, Sajjad I, et al. Evaluation of basil essential oils for antifungal and anti-aflatoxigenic activity against *Aspergillus flavus*. Sci Rep. 2025;15:6168. doi:10.1038/s41598-025-87397-7

[24] Arya R, Faruquee HM, Shakya H, Rahman SA, Begum MM, Biswas SK, et al. Harnessing the antibacterial, anti-diabetic and anti-carcinogenic properties of *Ocimum sanctum* Linn (Tulsi). Plants. 2024;13(24):3516. doi:10.3390/plants13243516

[25] Ghosal S, Bhowal J. A comparative evaluation of bioactive properties of raw, fermented, and germinated deoiled flaxseed flour extracts by different solvents. Int J Pharm Sci Res. 2023;14(7):3374-3391. doi:10.13040/IJPSR.0975-8232.14(7).3374-91.

[26] Kadam, s. A., salgar, s. S., patil, t. S., mane, o. A., & shewale, a. (2026). Overview on antifungal efficacy of ocimum species: a review of traditional use, mechanism of action, and potential as alternative therapeutics. *World*, *5*(2).

[27] Arisurya, I. G. N. K., Permatananda, P. A. N. K., Dewi, N. W. E. S., & Pandit, I. G. S. (2026). Antibacterial Activity of Tulsi Ethanolic Extract (Ocimum tenuiflorum L.) Against Staphylococcus aureus. *Jurnal Penelitian Pendidikan IPA*, *12*(1), 848-852.

[28] Funde S, Kelkar O, Katariya O, Baviskar A. The body's guardian: a review of Tulsi's (Ocimum sanctum) protective and modulatory pharmacology. J Ayurveda Integr Med Sci. 2026;10(12):108-119. doi:10.21760/jaims.10.12.17.

[29] Prakash, S., Singh, R. K., Dubey, K., & Mishra, N. (2026). Holy basil (Tulsi)–The sacred leaf in the management of type-2 diabetes. In *Indian Spices for Type 2 Diabetes* (pp. 275-298). Academic Press.

[30] Bura, P., Fatima, F., Srivastava, P., Siddiqui, M. H., Gupta, S., & Siddiqui, S. (2026). Ocimum-derived bioactive metabolites as next-generation antimicrobials targeting drug-resistant pathogens. *Plant Science Today*, *13*(2).

[31] Dahiya, D., Tripathi, S., Rani, K., Priyadarshini, A., Vibhuti, A., Gaur, P., ... & Pandey, R. (2026). Green synthesis of silver nanoparticles by using Ocimum sanctum and unveiling their antibacterial and antifungal properties. *Nano Trends*, 100220.

[32] Yang J, Bai J, Liu M, Chen Y, Wang S, Yang Q. Determination of phosphorus in soil by ICP-OES using an improved standard addition method. J Anal Methods Chem. 2018;2018:1324751. doi:10.1155/2018/1324751.